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# Friction-spinning – Interesting approach to manufacture of complex sheet metal parts and tubes

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**Abstract**

Friction-spinning is an innovative incremental forming process that permits the defined adjustment of material properties in a particularly precise manner. The process is characterised by the use of process elements from both metal spinning and friction welding. As the workpieces are being processed, friction sub-processes are employed to achieve self-induced heat generation. Compared with conventional spinning processes, this in-process heat treatment permits the extension of existing forming limits and allows more complex geometries to be achieved, together with defined, favourable part properties. The process thus holds a high potential for the manufacture of functionally graded workpieces, such as complex hollow parts made from tubes and sheets. In order to achieve functional gradation, i.e. to influence the material properties (strength or grain size) in a defined manner, it is essential to be able to set specific temperature profiles. It would be possible to influence these profiles by selecting appropriate process parameters like the feed rate, relative motion and the coefficient of friction. The process characteristics of friction-spinning make it eminently suited to tube processing. A further approach to the manufacture of parts with functionally graded areas is the use of sheet metal blanks as another semi-finished product. The paper will present the corresponding results of basic research into the manufacture of sheet metal parts with the aid of friction-spinning. Here, the influence of significant process parameters, forming strategies and tool systems on both the course and the outcome of the friction-spinning process will be shown. In addition, the differences and correlations that exist between tube and sheet processing will be described and discussed on the basis of parts made of tubes and sheets. These parts are manufactured by the friction-spinning process employing different process strategies and tool setups.


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## 1. Introduction

The requirement for a high performance, coupled with ecological concerns, such as for reduced material and energy consumption, calls for innovative lightweight products and hence for efficient manufacturing technologies (Kleiner et al., 2004). Promising lightweight structures include hollow components like those employed in the transportation sector and in general engineering (Finckenstein and Dierig, 1990). In conventional spinning processes, the forming limit of the workpiece is restricted due to the work-hardening effect that occurs during the process. An effective approach to counteracting and achieving these complex structures is the use of incremental forming processes combined with an extension of the forming limits through the use of heat treatment (Neugebauer et al., 2006 and Awiszus et al., 2005). Normally, this heat treatment is realized by burner systems, intermediate heating or the use of lasers (Bergs et al., 2005). All these approaches increase the costs associated with energy, investment and maintenance. Another approach is to use friction processes for the heat generation, which means that the process can then be referred to as friction-spinning. This combines elements of friction welding and a metal spinning process to achieve a localized warm-forming operation through the process-integrated friction. By selecting appropriate process parameters, defined temperature profiles can be set in the workpiece. As a consequence, it becomes possible to manufacture multifunctional components such as complex hollow parts made of tubes, profiles or sheet metal blanks with locally varying mechanical properties that satisfy the demands of lightweight design. The aim of the ongoing investigations is to extend the forming limits and achieve load-adapted workpieces with locally graded properties in aluminum, steel and stainless steel. The promising results from tube forming, such as the defined influence on the grain structure (Homberg and Lossen, 2013), hardness, residual stresses (Homberg and Hornjak, 2011), surface roughness (Homberg et al., 2012) and the high degree of deformation that is feasible for forming a wide range of new geometries (etc.) (Hornjak, 2013), constitutes the motivation for transferring the knowledge to sheet metal forming. The basic process principle of friction-spinning for a sheet metal component is shown in Fig. 1.

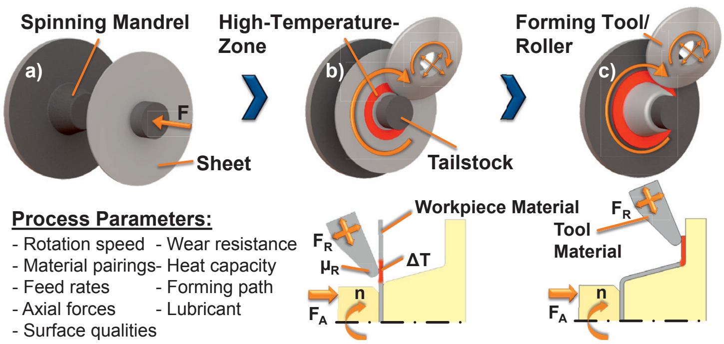


Fig. 1. Friction-spinning – principle behind the sheet metal forming process.

The sheet metal blank (Fig. 1 – a) is clamped with the aid of a tailstock, thus permitting the torque to be transferred. Once the blank has been brought to rotate, the friction-tool feed is activated, and the fixed tool comes into contact with the blank. Due to the friction induced by the relative motion, the temperature increases significantly (Fig. 1 – b). Consequently, the plasticity of the material is increased, thereby permitting high-degree forming operations (Fig. 1 – c). Additionally, tools can be used to support the forming process and/or the temperature generation/control (Homberg and Hornjak, 2011). With regard to the temperature, this can either be controlled in a defined manner over the entire process or be set according to the requirements by varying the rotation speed or the friction ratio, for example. Here, the friction ratio can be influenced due to the usage of different tool types and their relative motion between the sheet. It is possible to set a maximum dynamic friction with a stationary tool. Further with a rotating tool a minimal rolling friction can be realized. At the LUF, current research work is focusing on the development of friction-spinning tools and tool systems for the manufacture of complexly structured workpieces from tubes and sheets. This paper builds on the results obtained for tube forming, e.g. a high D/s and $D_1/D_0$ ratio for flange processing (Homberg and Lossen, 2013). These high D/s ratios make for a smooth transfer to sheet forming. A fundamental process investigation is conducted in a bid to achieve the maximum wall thickness reduction in cup forming through multi-pass forming strategies. In addition, the results of the influence of hardness and grain structure on the cup forming process are investigated and described.

## 2. Investigation of friction-spinning in sheet metal forming

Basically, the conventional spinning process is characterized by complex tool path geometries and the use of additional equipment e.g. a counterholder to form a cup, as is illustrated in Fig. 2 – 1a. This kind of process allows a maximum spinning ratio of 2.5 during the 1st pass on the basis of investigations of linear, quadratic, and involute tool paths (Kawai et al., 2002; Hayama et al., 1970). Hayama et al. (1970) clarified the typical non-constant wall thickness distribution of the conventional spinning process, which is due to the high tensile strain and can be influenced by the tool path geometry. A similar approach using a multi-roller head from Kawai et al. (2002) makes it possible to increase the spinning ratio to 3.3 using a single roller pass. An overview of the options for designing a spinning process is provided by Music et al. 2010. A considerable effort is required to form cup geometries with a height of 35 mm from an initial sheet metal blank in aluminum alloy 6082 (diameter of 120mm and a wall thickness of 5 mm) using a spinning mandrel with a diameter of 66 mm, and this can involve generating a complex tool path in synchronization with the counterholder. If an additional wall thickness reduction in the cup side wall is required, it is necessary to use multi-pass strategies (*cf.* Fig. 2 – 1b). A further approach to sheet metal forming is the friction-spinning process. This constitutes a good alternative on account of the linear tool path strategies and the low forming forces by contrast to conventional spinning. The sheet forming investigation shows the results for maximum wall thickness reduction, wall thickness distribution and the hardness and grain structure influence with less complex tool and tool path designs by comparison with conventional spinning processes. Also, the possibility of generating a gradation by adjusting the influence of the hardness or defined grain structure in cup forming is to be verified. The basic process principle behind the friction-spinning process is shown in Fig. 2.2(a-d).

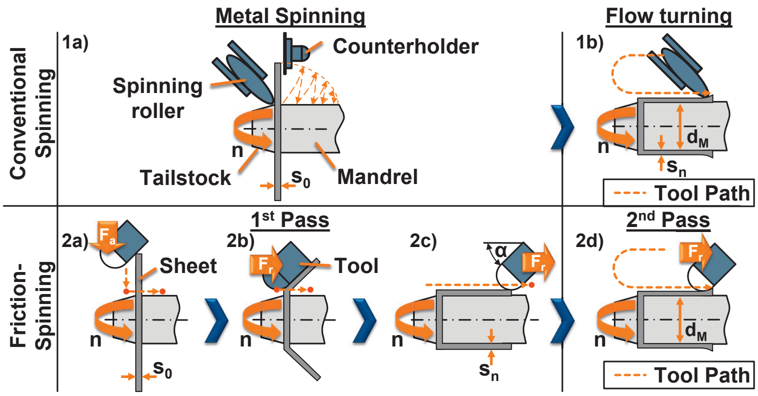


Fig. 2. Cup forming principle with a one-pass and two-pass forming strategy in conventional spinning and friction-spinning.

Here, a linear tool pass with a universal friction tool is used for the 1st pass. The process starts by bringing the sheet metal blank to rotate. The friction tool makes contact with the outer edge of the sheet due to a linear axial tool movement (Fig. 2.2 – a). The friction generated by the relative motion and the contact with the stationary tool causes the temperature in the forming zone to increase significantly. Once the required temperature level and the requisite material ductility are attained, the feed rate can be set to a higher level to form a conical intermediate geometry (Fig. 2.2 – b). The cup is formed by an ongoing linear radial tool movement, illustrated in Fig. 2.2 - c. A further adjustment of the resulting wall thickness $s_n$ on the side wall of the cup can be achieved by setting an adequate gap between the mandrel and the tool directly in the 1st pass. The process strategy can be extended with a 2nd forming pass and is shown in Fig. 2.2-d. The 2nd pass involves a further overrun forming step following the first radial tool movement to form the cup geometry (Fig. 2.2). In the 2nd pass, it is possible to select the desired friction ratio. This can be varied between the minimum friction ratio (rotating tool) and the maximum friction ratio (stationary tool) and has a significant influence on the microstructure and hardness (*cf.* Chapter 2.1 and 2.2). Further, the tool angle α in Fig. 2.2 is set to 45° due to experimental investigations which have shown that an angle of 45° constitutes a good compromise between the forming forces and the material flow (Homberg et al., 2012; Hornjak 2013). In special cases a tool with 0° and 90° degrees can be used for manufacturing by means of an axial upsetting forming operation to produce a pulley, for example.

### *2.1. Wall thickness reduction and grain structure influence*

This chapter deals with the manufacture of tall cups with thin wall thicknesses without a complex tool path strategy or the use of multi-pass strategy to avoid the problem of local thinning in the cup side wall. The corresponding investigation starts with the analysis of the maximum possible wall thickness reduction due to different parameters (rotation speed/feed rate) and forming strategies 1st and 2nd pass described above (*cf.* Fig. 2.2). The spinning ratio is about 1.8 in this investigation, and the resulting D/s ratio is nearly 4 without the additional and customary roller overruns or counterholder (Music et al., 2010). Furthermore, the process forces do not exceed 3 kN and are thus insignificant by comparison to conventional spinning. In Fig. 3, two typical thickness distributions are illustrated along the cup side wall with the minimal wall thickness for one and two-pass strategies. The minimum wall thickness of 78.5 % ($\varphi_s$ = -1.5) compared to the initial wall thickness was observed in the bottom radius region using a single-stage strategy, as shown in Fig. 3 (a). Using this strategy, an increase in the thickness at the end of the cup sidewall was observed as a general trend. At this point, the wall thickness reduction is 62.2 % ($\varphi_s$ = -1).

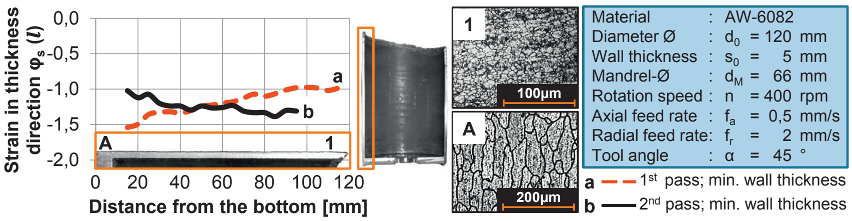


Fig. 3. Grain structure influence and maximum wall thickness reduction of cup forming process with one and two-pass forming strategy.

The reduction in the wall thickness at the beginning results from the engagement of the residual material with the tool. The resulting tensile strain due to the radial movement from the tool in combination with the friction and material ductility generates longitudinal stretching in this area (15 mm) of the cup. This effect results in thinning near the bottom and will decrease if less sheet material is in contact with the tool. Ultimately, the aforementioned section of the cup marks the limited area in which the maximum reduction can be achieved with a one-pass forming strategy. In contrast to the one-pass strategy, the 2nd pass (b) shows the opposite trend. Here, the maximum reduction is at the end of the cup and amounts to 75 % ($\varphi_s$ = -1.4). Hence, the minimal wall thickness reduction is in the bottom region and is nearly 65 % ($\varphi_s$ = -1.05). The maximum reduction in the 2nd pass is limited due to the constant increase in the temperature in the mandrel and sheet due to the longer manufacturing time and the prevailing friction. All in all, the maximum wall thickness reduction was achieved with a one-pass strategy and produces taller cups (115 mm) than a two-pass strategy (95 mm). Basically, a significant constant wall thickness profile can be observed with two-pass forming strategies. The influence on the grain structure of the workpiece with the one-pass strategy is illustrated in Fig. 3 (A and 1). The friction-spinning process generated grain refinement due to the high shear loads and the high temperature of this thermo-mechanical process (Homberg and Lossen, 2013). The initial grain structure of the AA-6082 material used has a grain size of approx. 100 – 150 µm and is oriented in the direction of rolling (*cf.* Fig. 3 – A). By contrast, the grain structure in area 1 is significantly influenced and is adjusted in a range of 5 – 15 µm. It is the same grain refinement effect as in tube processing and is dependent on the time for which the temperature load acts and the degree of deformation. Further investigations will be conducted in future studies into the defined influencing of the grain structure so as to generate an approximately ultra-fine grain structure with multi-axial forming strategies taken from tube processing (Homberg and Lossen, 2013).

*2.2. Analyses of the hardness adjustment*

A further focus of investigation is a define influencing and adjustment of hardness in the manufactured workpieces. Previous hardness investigations conducted for the tube forming of aluminum alloy 6082 show that a defined and locally restricted influence of the workpiece properties is readily possible (Homberg and Hornjak, 2011; Hornjak, 2013). Fig. 4 shows the resulting hardness distributions of the specimens referred to above. The initial hardness of the material depends to a significant extent on the process characteristics of the friction-spinning process. The high temperature and the high degree of deformation give rise to grain refinement (*cf.* chapter 2.1) that also has an influence on the hardness reduction of the formed material.

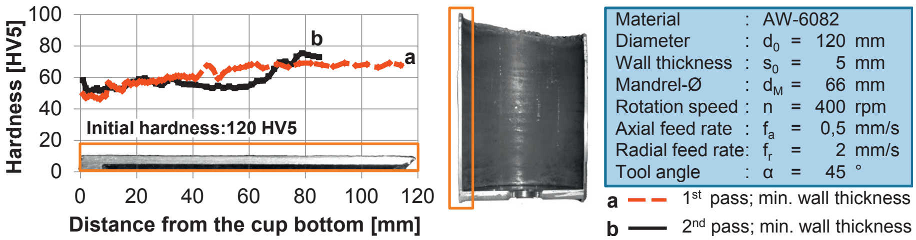


Fig. 4. Process strategy influence on the hardness distribution.

The hardness distribution of the 1st pass (a), with the maximum wall thickness reduction, involves an increase in the hardness from 50 HV5 to 70 HV5, starting at the bottom of the cup. If a two-pass strategy (b) is used, the hardness distribution remains more consistently at a level of 55 HV5 from the beginning, ending near the end of the cup. This effect of a hardness increase at the end of the specimens always occurs, since it is caused by the temperature drop at the end of the forming process. This is because of the reduced amount of forming material which is in contact with the tool and the lack of material resistance for generating the required temperature. Here, the effects of a warm rolling process result, leading to an increase in the hardness. The adjustability of the hardness in sheet forming is shown in Fig. 5. This illustrates three forming strategies (a - c) which have the same parameters and give rise to the same wall thickness reduction in this forming process. The process strategies are varied, with a one or two-pass strategy and with a maximum or minimum friction ratio.

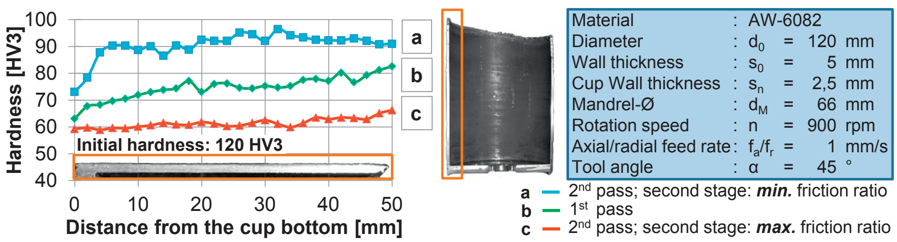


Fig. 5. Possibility of hardness adjustment with an aluminum alloy 6082.

Fig. 5 – b shows the hardness distribution for a one-pass strategy with an end wall thickness of 2.5 mm. The 1st pass investigations show a hardness adjustment in a range of 10 HV5 with a parameter variation of only the rotation speed (*n*) and the feed rate ($f_a/f_r$). If a significant hardness influence is desired, the two-pass strategy has to be applied. Fig. 5 – a/c shows the maximum hardness adjustment range using the two-pass strategy. The 2nd pass can be applied with a minimum or maximum friction ratio. Fig. 5 – a illustrates the 2nd pass with the minimum

friction ratio. This strategy results in the maximum hardness attained, which is about 20 HV3 higher than the single stage. The other two-pass strategy with the maximum friction ratio generates the lowest, but constant hardness distribution. The minimum hardness results in the range of 60 HV3 and is on average 15 HV3 lower than for the single-stage forming process. Finally, the hardness in the cup forming process can be adjusted within a range of 35 HV3.

## 3. Conclusion

The friction-spinning process is an interesting approach which holds a high potential for the production of new and complex geometries with functionally graded properties in the tube and sheet forming of aluminium alloys. The possibility of extending the forming limits of conventional metal spinning processes through in-process heat generation is examined, making it possible to achieve a cup forming process with a high wall thickness reduction in one or two forming steps. This paper describes a maximum reduction to approximately 80 % of the initial wall thickness. Additionally, the thickness of the cup side wall can be adjusted through the infeed of the tool to the mandrel. Further, this paper shows that it is possible to achieve a defined adjustment of the hardness distribution through parameter variation and special process strategies in sheet metal forming. Also, it has been possible to verify the basic influence on the grain structure in sheet metal forming which characterizes the friction-spinning process. To conclude, friction-spinning is an innovative forming technology that expands the existing forming limits and holds a high potential for the efficient manufacture of the lightweight structures of tomorrow made from tube and sheets.

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